EFFICACY OF LASER FLUORESCENCE IN DENTAL CARIES DIAGNOSIS:

A META-ANALYSIS

by

Derek T. Fagen
LCDR, DC, USN

A thesis submitted to the Faculty of the
Comprehensive Dentistry Graduate Program
Naval Postgraduate Dental School
Uniformed Services University of the Health Sciences
in partial fulfillment of the requirements for the degree of
Master of Science
in Oral Biology

June 2012

Naval Postgraduate Dental School
Uniformed Services University of the Health Sciences
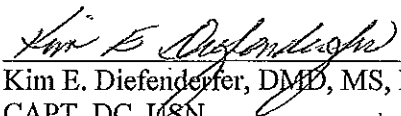Bethesda, Maryland

CERTIFICATE OF APPROVAL

_____

MASTER'S THESIS

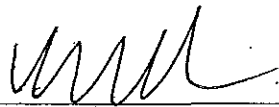_____

This is to certify that the Master's thesis of

Derek T. Fagen

has been approved by the Examining Committee for the thesis requirement
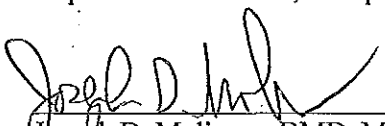for the Master of Science degree in Oral Biology at the June 2012 graduation.

Thesis Committee:

_____
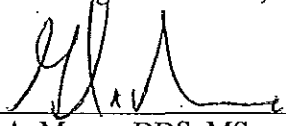
Kim E. Diefenderfer, DMD, MS, MS
CAPT, DC, USN
Thesis Supervisor

_____

Vlasta Miksch, DDS, MS
CAPT, DC, USN
Department Chairman, Comprehensive Dentistry

_____

Joseph D. Molinaro, DMD, MS
CDR, DC, USN
Graduate Program Director, Comprehensive Dentistry

_____

Glen A. Munro, DDS, MS
CAPT, DC, USN
Dean, Naval Postgraduate Dental School

NAVAL POSTGRADUATE DENTAL SCHOOL
DEREK T. FAGEN

2012

ABSTRACT


EFFICACY OF LASER FLUORESCENCE IN DENTAL CARIES DIAGNOSIS:
A META-ANALYSIS

DEREK T. FAGEN
MASTER OF SCIENCE, COMPREHENSIVE DENTISTRY, 2012


Thesis directed by:    KIM E. DIEFENDERFER, DMD, MS, MS
                       CAPT, DC, USN
                       PROFESSOR, DENTAL RESEARCH
                       NAVAL POSTGRADUATE DENTAL SCHOOL

Introduction:  The ability to accurately diagnose the presence or absence of dental caries is of the utmost importance since errors may lead to either performance of irreversible, but unnecessary, dental procedures, or failure to provide needed treatment. Conventional caries detection methods (visual/tactile/radiographic) rely on subjective judgment and are prone to misinterpretation.  To improve accuracy, several adjunctive diagnostic instruments are available.  Of these, laser fluorescence has received the most attention.  However, a majority of studies possess shortcomings in methodology that limit their value.  As a result, the plethora of conflicting reports in the scientific literature renders it difficult for practitioners to make confident, informed decisions regarding the effectiveness of these instruments.

Objective:  This meta-analysis sought to evaluate the effectiveness (sensitivity and specificity) of laser fluorescence, as compared to other diagnostic methods (visual/tactile examination; bitewing radiographs; fiber-optic transillumination) in the detection of dental caries.

Methods: A PubMed search of the relevant English language literature published between 1985 and April 2012 was conducted using variations of the following key terms: caries diagnostic methods, visual/tactile detection, FOTI, fiber optic transillumination, bitewing radiographs, laser fluorescence, and DIAGNOdent. This initial search identified 6,489 citations. Applying several inclusion and exclusion criteria followed by title and abstract reviews, and finally, full manuscript review yielded 28 publications. To facilitate comparisons among studies, we converted the sensitivity and specificity values of each diagnostic test to their standard scores, or normal deviate values (Z values). Mean ($\pm$ standard deviation) $D_z$ values were calculated for each diagnostic method and compared via a multivariate analysis of variance (MANOVA).

Results: MANOVA revealed no statistically significant differences in $D_z$ values among any of the four diagnostic methods evaluated.

Conclusion: As compared to other methods, laser fluorescence appears to neither enhance nor hinder the accuracy of caries diagnostic decisions.

TABLE OF CONTENTS

## LIST OF TABLES

# LIST OF FIGURES

CHAPTER 1: REVIEW OF LITERATURE

Modern management of dental caries relies upon diagnosis of the disease process and detection of pathologic changes (i.e. lesion formation) in their earliest stages (1). Bader, Shugars and Bonito described the diagnosis of dental caries as "an exhaustive search for evidence of demineralization on individual tooth surfaces" (2). The traditional methods that dentists, particularly in the U.S., use in the diagnosis of caries lesions involve visual and tactile examination combined with radiographic assessment. Explorers are used to probe accessible smooth and fissured surfaces and restoration margins, while radiographs are used to assess proximal surfaces. For many years, refinement of technique, rather than development of new technology, characterized these methods (3).

While perhaps a seemingly basic skill, the diagnosis of dental caries can be quite difficult, even for experienced clinicians. Differences among dentists in diagnostic decision-making are often considerable because our diagnostic methods "depend on subjective interpretation of subtle visual and tactile cues" (2). In a study analyzing the variation in dentists' clinical decisions for treatment, Bader and Shugars (4) discussed that the age of the practitioner, clinical experience, educational background, region of practice, and patient population all influence the decision-making process. The effects of these decisions are evident in the early stages of diagnosis of dental disease, as seen, for example, when one provider decides to monitor and remineralize a caries lesion, while another practitioner feels the best decision is to restore the lesion. In another study, Shugars and colleagues (5) studied the proportion of large restorations that were diagnosed as needing crowns among 100 practices in four regions of the United States.

Results revealed a threefold difference in this proportion across the different regions. Decisions for irreversible care should be based on what is best (in terms of function, economy, and longevity) for the patient, considering the 'do no harm' (6) concept. With all factors (e.g., differences in clinicians' diagnostic abilities, educational backgrounds, and clinical experience, as well as differences in opinion) considered, variations in diagnoses and treatment methods can be diverse within the dental community.

As seen in many aspects of our professional and personal lives, computerized and technical devices are on the rise and in demand. As related to dentistry, some of these devices are intended to aid the practitioner in caries detection by providing supplemental diagnostic information to reinforce clinical decisions and, ultimately, reduce or minimize the amount of human error. There is a definite need for improved accuracy in caries diagnosis; a possible solution may lie in the development and refinement of these diagnostic technologies. We see this occurring in the dental market today as more technological caries detection devices are available; however, we need to know if they offer consistent results.

Changing Epidemiology of Dental Caries

Caries diagnosis is further complicated by the epidemiologic changes in dental caries experience observed in recent decades. Several reports have confirmed that during the last three decades there has been a dramatic reduction in the prevalence, incidence, and severity of dental caries throughout most of the developed world (7-12). This trend is generally attributed to the widespread adoption of public water fluoridation programs and the use of fluoridated dentifrices (9, 13, 14). However, dental caries remains one of

the most prevalent diseases worldwide, with 91% of adults experiencing at least one caries lesion in their lifetimes (8, 15).

Bader and Brown (3) discussed how changes in caries experience (lower) and progression rate (slower) have affected the diagnosis and treatment of caries in several ways. As caries prevalence decreases, the likelihood of making a false-positive diagnosis increases. Because no diagnostic test is 100% accurate, all tests will result in some level of false-positive, as well as false-negative diagnoses (16). In the coming years, as fewer teeth have caries, false-positive diagnoses will likely account for an even greater proportion of all diagnoses made (3). Moreover, as the relative distribution of caries has changed, the occlusal surface, rather than the interproximal, has become the most affected site, accounting for over 80% of all caries lesions in both children and adults (17). Proximal surfaces present challenges to accurate diagnosis because of their limited access for visual inspection. Bitewing radiographs are essential in detecting lesions that are hidden from direct examination; however, even slight overlapping of interproximal areas may render radiographs ineffectual (16). Occlusal surfaces present their own unique diagnostic challenges due to their irregular anatomy, variable enamel thickness, and capacity for partial remineralization, which can mask underlying "hidden caries" in dentin (18). Although radiographs are indispensible in caries diagnosis, they cannot accurately detect early enamel lesions (16). Moreover, radiographic films can be of limited value in the diagnosis of secondary caries because of the obscuring effect of the restorative material (19).

Because caries lesions progress at slower rates today, the astute clinician should consider the possibility of preventive, rather than restorative, therapy. Caries lesions can

be arrested and, in some cases, reversed (9).  Slower progression rates provide enhanced opportunity for success in sealing at-risk occlusal surfaces and remineralizing incipient smooth surface lesions; therefore, monitoring at regular intervals over time can be crucial to determining disease activity and the need to restore (3).  The availability of fluoride (through drinking water and over-the-counter dental products) has changed the behavior of caries lesions dramatically (20).  In a study by Hopcraft and Morgan (21), patients with no lifetime exposure to fluoridated drinking water were twice as likely to have interproximal lesions compared to individuals with a lifetime exposure to fluoridated drinking water.  Differentiation between progressing and arrested lesions is essential for appropriate treatment.  Arrested lesions were once active carious sites which have become non-active and present the possibility of remineralization.

Progression of caries lesions, even at a slow rate, leads to morphologic changes (demineralization) in enamel, making diagnosis difficult.  With these lesions, there is a substantial risk of damaging demineralized enamel surfaces when using an explorer for tactile examination.  Depending on the sharpness of the explorer, depth and width of pits/fissures, and amount of tactile pressure used, affects the clinician's ability in diagnosing the presence of caries lesions (22).  Ekstrand, Qvist, and Thylstrup (23) demonstrated the harmful effects on demineralized enamel that can occur while using an explorer in examining fissures.  Similarly, van Dorp, Exterkate, and ten Cate (24) demonstrated that damage from an explorer on demineralized enamel can actually increase the growth of the caries lesion.

Accuracy of Diagnostic Tests

Any diagnostic test will produce one of four possible outcomes, only two of which are potentially correct. The accuracy of a diagnostic test is typically described in terms of four parameters: (1) sensitivity (Sn); (2) specificity (Sp); (3) positive predictive value (PPV); and (4) negative predictive value (NPV) (Table 1) (25).

Table 1. Diagnostic test characteristics and definitions (25).

| Diagnostic Test Result | Actual Condition (Disease) | |
| --- | --- | --- |
| | Positive | Negative |
| Positive | True Positive (A) | False Positive (B) |
| Negative | False Negative (C) | True Negative (D) |

Sensitivity = A / (A + C)          Positive Predictive Value = A / (A + B)

Specificity = D / (B + D)          Negative Predictive Value = D / (C + D)

*Sensitivity* is the proportion of diseased persons in a screened population who are identified as such by the screening test; sensitivity represents a test's ability to correctly identify disease when it is present.

*Specificity* is the proportion of truly non-diseased persons in a screened population who are identified as such by the screening test; specificity represents a test's ability to correctly identify the absence of disease when it, indeed, is not present.

*Positive predictive value* is the probability that a person with a positive test result does have the disease.

*Negative predictive value* is the probability that a person with a negative test result truly does not have the disease.

*Accuracy* is the degree to which a measurement, or an estimate based on more than one measurement, represents the true value of the attribute being measured, i.e., "the proportion of all test results, both positive and negative, that are correct" (25). For a diagnostic test, accuracy is often defined as the combination or sum of sensitivity plus specificity.

Misdiagnosis – in either direction – results in undesirable consequences. A false positive diagnosis is a positive test result in a subject who, in fact, does not possess the attribute (e.g., disease) for which the test is conducted. A false negative diagnosis is a negative test result in a subject who actually possesses the attribute for which the test is conducted (25). For dental caries, a false-positive diagnosis may result in unnecessary irreversible restorative procedures because clinicians assume that active caries lesions are present when, indeed, they are not. A false negative diagnosis leads to untreated active decay and allows for progression of caries lesions.

Clinical Methods of Caries Diagnosis

The traditional method of caries diagnosis involves the use of visual and tactile examination, usually combined with radiographic images. Fracaro, Seow, McAllan, and Purdie (26) examined 481 children (ages 5-12 yrs) and 1,929 occlusal surfaces of first and second permanent molars. The study involved five clinicians and revealed that 96% of the teeth scored by clinicians as having caries matched the radiographic findings. However, the specificity was found to be 0.58, meaning the clinicians' diagnoses correctly identified only 58% of the caries-free surfaces. Hopcraft and Morgan (21) evaluated 973 Australian Army recruits using visual/tactile inspection and bitewing radiographs. In this study, the clinical diagnostic criteria for dental caries were visually

6

apparent cavitation, discoloration through enamel, or visual evidence of recurrent caries.

Radiographic assessment evaluated the extent of radiolucency into the enamel and dentin.

Twenty repeat blind examinations were conducted by each examiner on four occasions to

measure intra-examiner reliability. Three examiners were used, and the results showed

the use of bitewing radiographs identified more than 2/3 of the interproximal lesions that

were missed compared to visual/tactile alone.

Valera and colleagues (27) examined 72 extracted permanent molars for extent of

caries lesions. Inter-examiner reproducibility by visual inspection alone, which included

two exams, was 0.61 and 0.53, while radiographic inspection resulted in a reproducibility

of 0.22 and 0.32. Braga and colleagues (28) assessed the reliability of conventional

diagnostic methods in detecting secondary caries. Fifty-four primary molars

(extracted/exfoliated) were evaluated by two dental examiners using conventional

methods. Inter-examiner agreement for visual examination in enamel and dentin was

0.71/0.88. The agreement for tactile was 0.86 (enamel)/0.69 (dentin) and for

radiography among the examiners was 0.48/0.55, respectively. Both of the previously

mentioned studies reveal that conventional diagnostic methods still result in inconsistent

diagnoses by practitioners.

Lussi (29) demonstrated that many occlusal caries lesions (still in enamel) cannot

be discovered by visualization and probing alone. In this study, 34 dentists (16 private

practice dentists and 18 dentists employed at the University of Bern, School of Dental

Medicine) evaluated the occlusal surfaces of 61 (54 molars, 7 premolars) extracted

posterior teeth. After histologic preparation and evaluation of the specimens, the

percentage of clinically correct treatment decisions was determined to be 73%. Mean

sensitivity and specificity were 62% and 84%, respectively; the dentists were more likely not to treat decayed teeth than to restore sound teeth.

Adjuncts for Caries Diagnosis

*Illumination and magnification*.  Today, it is very common for providers to use illumination and magnification during examination and treatment.  In a study conducted by Maggio, Villegas, and Blatz (30), preclinical dental students using magnification completed more preparations, worked more quickly per procedure, and used the computer-assisted evaluation (comparison of student's preparations to 'ideal' preparations) less frequently and for shorter periods.  According to Friedman (31), appropriate visual enhancement should be considered for all dental professionals to make the practice of dentistry more precise and to reduce the risk of musculoskeletal injury.

Eichenberger and colleagues (32) discussed the higher visual acuity achieved while using magnification devices.  In this study, dentists used loops ranging from a single lens loupe 2x, Galilean loupe 2.5x, and the Keplerian loupe 4.3x compared to unaided visual acuity.  The Keplerian loupe obtained the highest visual acuity (measured with miniature E-optotype tests on a negatoscope) followed by the 2.5x loupes, 2.0x loupes, and single lens loupe; unaided vision provided the lowest acuity.  Christensen (33) believed he achieved a higher level of quality in his dentistry when using magnification.  However, there is little quantifiable objective evidence that illumination and magnification, individually or in combination, significantly improve clinicians' diagnostic accuracy.

*Digital Radiography*.  Radiographic technology has improved with the advent of both high speed radiographic films and especially with the use of digital imaging,

reducing radiation doses and producing diagnostic films almost instantly. The immediate viewing of the image is a significant clinical advantage, along with the ability to change contrast (lighten or darken) and enlarge images. Digital radiography eliminates the need to maintain developer and fixer solutions and allows for storage of images on a computer database, thus making consultation with other practitioners more convenient (34).

The difficulty of precise caries detection is related to factors such as the complex anatomy of pits and fissures (35) and superimposition of structures in the radiographic evaluation (36). Moreover, radiographs underestimate the extent of demineralization and are unable to reveal the earliest stages of dental caries (37). Anbiaee and colleagues (38) reported that digital and conventional bitewing radiographs had similar diagnostic accuracy for the detection of recurrent caries. In this laboratory study, digital and conventional radiographs were made following placement of interproximal amalgam restorations and production of simulated secondary caries lesions. The overall accuracy, as determined by three expert observers, was 76% for digital and 75% for conventional radiography. However, because digital radiography required less ionizing radiation, the authors recommended this method of imaging for routine dental care. Similarly, Dias da Silva and colleagues (39) reported that digital radiography was as accurate as conventional radiography and visual inspection of primary teeth with occlusal caries when dentin is involved. Digital radiography revealed a sensitivity of 0.68 (into dentin) for both examiners, and a specificity of 0.90 and 1.0, respectively, for each examiner. Conventional radiography results were 0.74 (examiner 1) and 0.79 (examiner 2) for sensitivity and 0.87 (examiner 1)/0.94 (examiner 2) for specificity. Chong and colleagues (40) reported sensitivities of 0.81 and 0.90 for clinical examinations

conducted with conventional and digital radiography, respectively.  In this study, 320

extracted premolars were examined using an explorer, followed by an examination using

laser fluorescence.  The teeth were then exposed using conventional and digital

radiography.  The gold standard of histological sectioning of the teeth was not performed

in this study due to the large number of specimens.  Rather, the authors used the

Spearman rank correlation to assess how well the different diagnostic methods correlated

to each other.  The sensitivity of the clinical exam with conventional films was 0.81,

while the specificity was determined to be 0.44.  The visual-tactile exam with digital

radiography resulted in a sensitivity of 0.90 and a specificity of 0.44.  Laser fluorescence

along with visual-tactile examination revealed a sensitivity and specificity of 0.89 and

0.56, respectively.

Technologic Aids in Caries Diagnosis

 *Fiber-optic Transillumination*.  Fiber-optic transillumination (FOTI) is a visual

inspection technique that uses the light scattering properties of enamel to visualize

density variations in tooth structure.  When light is passed perpendicular to a suspected

caries lesion, the light becomes scattered due to a change in density of the tooth structure

(demineralized areas are not as dense); the resulting contrast is used to detect the caries

lesion.  Digitized fiber-optic transillumination (DI-FOTI) is similar to FOTI, but images

are collected and transmitted to a computer monitor for evaluation (41).  In a study by

Cortes, Ellwood, and Ekstrand (42) involving 111 extracted permanent molars, FOTI

accurately identified 50% of the sound sites and 66% of lesions into dentin.  Hintze,

Wenzel, Danielson, and Nyvad (43) found in an *in vivo* study involving 338 unrestored

interproximal posterior surfaces, that using FOTI revealed a sensitivity ranging from 0.00

to 0.08 and a specificity of 0.99 to 1.00 among four clinicians.  It was demonstrated that the lesions detected in enamel by FOTI were found to be in dentin on the bitewing radiographs.  The authors concluded that due to its low sensitivity and positive predictive values, FOTI should be used as only a supplemental diagnostic tool for diagnosis of interproximal caries lesions.  In contrast, Mitropoulos, whose *in vivo* study included 1,042 tooth surfaces and one examiner, concluded that FOTI significantly improved the detection of interproximal caries (44).

*Electrical Conductance/Resistance*.  Electronic Caries Monitor (ECM) and Electrical Impedance Spectroscopy (EIS) are two methods that employ electrical measurements in diagnosing dental caries.  ECM uses a single fixed frequency alternating current to measure bulk resistance of tooth structure, while EIS measures the dielectric properties of a medium (e.g., tooth structure) as a function of frequency.  The main advantage of EIS over ECM is that since materials exhibit different electrical responses at different frequencies, EIS can help determine more accurately the various densities which demonstrate these differences.  Several factors affect electrical measurements of teeth: the porosity of the tissues; the surface area of the electrical contact; the thickness of the tissues; the extent of hydration of tissues; and the temperature and concentration of the ions in the fluid within the tooth.  As a tooth demineralizes, it becomes more porous. These porosities become filled with fluids (saliva) that contain ions, which leads to increased electrical conductivity (45).  Longbottom (45) reported that ECM measurements, which apply to occlusal sites only, can vary according to the relative occlusal to interproximal smooth surface caries ratios for prevalence or incidence in patients.  In an *in vitro* study, Lussi and colleagues (46) found that ECM had a specificity

range of 0.64 to 0.78 and a sensitivity range of 0.87 to 0.92. This study involved 11

dentists who recorded two different measurements (one with laser fluorescence and one

with ECM) on 83 extracted molar teeth. When compared to laser fluorescence, ECM had

lower diagnostic validity based on the sensitivity and specificity values (46). In contrast,

Huysmans, Longbottom, and Pitts (47) found that electrical methods and bitewing

radiography showed higher sensitivity and lower specificity than visual inspection, and

that the overall diagnostic performance of electrical measurements was superior to visual

inspection alone.

*Laser Fluorescence*. The presence of bacterial metabolites has been used as a

marker, or surrogate, for caries, and a workable system using this technology is

commercially available. Bacterial metabolites within caries lesions produce fluorescence

that can be enhanced by laser light (48). DIAGNOdent (KaVo, Lake Zurich, IL)

generates laser light with a wavelength of 655 nm. The laser light is absorbed by both

organic and inorganic materials in the teeth, and re-emitted as fluorescence within the

infrared range. In the presence of dental caries, fluorescence increases, and the change is

registered as an increased digital number and indicated acoustically (49).

Numerous studies have evaluated the efficacy of laser fluorescence. Results have

been equivocal. Bader, Shugars and Bonito (2) concluded that DIAGNOdent is more

sensitive than traditional visual and tactile diagnostic methods; however, the increased

likelihood of false positive diagnoses, compared with that of visual methods, limits its

usefulness as a principal diagnostic tool. Similarly, Bamzahim and Angmar-Mansson

(50) concluded that DIAGNOdent should be used only as an adjunct to conventional

methods in determining the presence of secondary caries. In this study, restorative

materials produced little or no fluorescence, thus blocking potential caries readings by DIAGNOdent. Staining, often evident around restorations, resulted in higher DIAGNOdent readings, leading to more false positive readings. Apostolopoulou, Lagouvardos, Kavvadia, and Papagiannoulis (51) reported that laser fluorescence (DIAGNOdent) had better sensitivity (0.90) than specificity (0.36) for enamel lesions and better specificity (0.91) than sensitivity (0.36) for lesions into dentin. With this study, 24 extracted primary molars were examined by one clinician using direct and indirect visualization, radiographs, and laser fluorescence.

In another study, Bamzahim, Abdulaziz and Shi (52) evaluated the detection of secondary caries lesions around amalgam restorations using DIAGNOdent, visual, tactile, and conventional radiographic means. This study showed the sensitivity and specificity of DIAGNOdent and conventional radiography were 0.60/0.81 and 0.56/0.92 respectively, while sensitivity and specificity of visual inspection were 0.44 and 0.96. Of the 51 restored teeth used in this study, 29% had staining around the restoration margins. All of the teeth that resulted in a false positive diagnosis with DIAGNOdent had stained margins. The authors concluded that DIAGNOdent should be used only as an adjunct to conventional methods when detecting secondary caries around amalgam restorations. Diniz and colleagues (53) examined the influence of clear and opaque sealants on laser fluorescence (LF) caries detection success, and found that opaque sealants decreased fluorescence significantly in comparison to clear sealants. A possible explanation to this is that titanium dioxide (pigment) could absorb either the light emitted by the devices or the fluorescence emitted by the carious tissue (54).

In contrast, Lussi and Francescut (55) evaluated 95 deciduous teeth (extracted – *in vitro*) via visual inspection, visual inspection with magnification, visual inspection combined with light pressure probing, bitewing radiography, and laser fluorescence (DIAGNOdent). In comparison to conventional clinical methods, laser fluorescence showed a significantly greater ability to detect dentinal lesions in deciduous teeth. The authors concluded that DIAGNOdent could be used as an additional tool in the detection of occlusal caries in deciduous teeth, and its good reproducibility should enable the laser device to monitor the caries process over time.

Boston (56) performed an *in vitro* study using laser fluorescence to detect secondary caries lesions around resin composite restorations. Fifteen extracted teeth were examined using DIAGNOdent and then sectioned for histologic evaluation. The histologic incidence was 20% for enamel caries and 36.7% for dentin caries. With DIAGNOdent, the sensitivity and specificity were 0.67/0.79 and 0.73/0.84 for enamel and dentin lesions, respectively. The author concluded that DIAGNOdent may have potential for detecting secondary caries adjacent to resin composite restorations and that further research is needed with DIAGNOdent for its use around restorative materials.

Cortes and colleagues (42) performed a study that involved 111 extracted molar teeth and five diagnostic methods to include visual, FOTI, combined FOTI/visual, laser fluorescence (DIAGNOdent), and the Electrical Caries Monitor. DIAGNOdent showed a sensitivity of 0.72 and a specificity of 0.91, while the ECM had corresponding values of 0.90 and 0.83. Visual examination revealed sensitivity and specificity values of 0.96 and 0.57; FOTI of 0.96 and 0.74; and combined FOTI/visual values of 0.94 and 0.70. The authors believe that in a clinical setting it is inappropriate to apply cut-off values without

first considering the caries risk profile of the individual patient; therefore, they suggested that ECM and laser fluorescence can be useful in monitoring progression of lesions, but using these devices alone without clinical examination should be avoided. Lussi, Hibst and Paulus (57) advised that the decision to begin restorative treatment should not be based solely on laser fluorescence readings; the clinician must also consider the patient's case history, perceived caries activity, and the status of the surface (intact or cavitated), as well as fluoride and dietary status.

*Laser Light and Heat.* Light of various wavelengths has been used to penetrate tooth structure and cause enamel fluorescence, which can then be visualized and measured. The Canary Dental Caries Detection System (Quantum Dental Technologies; Toronto Canada) is a new (2010) device for the early detection and monitoring of caries lesions. According to the manufacturer's claims, this instrument can detect decay on smooth enamel surfaces, root surfaces, occlusal and interproximal surfaces, and around existing amalgam or resin composite restorations. The Canary System uses a low-power, pulsating laser light to scan teeth for the presence of dental caries. The laser light is absorbed by the tooth and two phenomena are observed: (1) the light is converted into luminescence, and (2) there is a release of heat (less than 1 degree Celsius). This heat will not harm the tooth, and simultaneous measurement of the reflected heat and light provides information on the presence and extent of teeth decay below the tooth surface. The Canary System is commercially available in Canada. Performance data are limited to the manufacturer's claims (58); there are currently no published independent laboratory or clinical evaluations of this system.

Summary

Caries diagnosis remains one of the most challenging aspects of clinical practice. Whether trying to interpret radiographs with superimposed structures or attempting to diagnose caries lesions in occlusal grooves with an explorer, there are errors that occur. When weighing the clinical implications of false-positive and false-negative diagnoses, one must consider the consequences of performing unnecessary dental procedures, as well as the potential harm of failing to treat active disease. When caries are left untreated, this allows for further progression of lesions and destruction of tooth structure. Conversely, treatment of teeth that do not need restorative intervention leads to a financial burden on patients, irreversible damage to teeth, and the likelihood of re-restoration in subsequent years.

Due to shortcomings in conventional caries detection methods (visual; tactile; radiographs), there is a need to find an adjunctive diagnostic aid that can give consistent results. There are several caries diagnostic aids commercially available. These systems attempt to improve diagnostic accuracy; however, numerous past studies using these devices reveal variable and inconsistent results; moreover, variations in study methodologies make comparisons from one study to another difficult. As a result, the current literature can be quite confusing. The ideal caries diagnostic system must provide consistently accurate performance in a variety of clinical situations, which may include permanent and deciduous teeth; occlusal, proximal, and smooth surfaces; primary and secondary caries; non-restored teeth, as well as those restored with a variety of metallic and non-metallic materials. High sensitivity and high specificity are absolute requirements. Of the various caries diagnostic systems available, laser fluorescence (e.g., DIAGNOdent) has received the most attention. However, a majority of studies possess

shortcomings in methodology that limit their value (2, 16). As a result, the plethora of contradictory reports in the scientific literature renders it difficult for practitioners to make confident, informed decisions regarding the effectiveness of these products. Therefore, the purpose of this study is to evaluate the past studies via meta-analysis to compare the traditional diagnostic methods of visual/tactile, radiographs, FOTI, and laser fluorescence to determine which methods, or combination of methods, produce the greatest accuracy in caries detection.

CHAPTER II: MATERIALS AND METHODS

We sought to answer the question, "What is the validity of laser fluorescence, as compared to other diagnostic methods, for detecting caries lesions in permanent teeth?" A PubMed search of the relevant English language literature published between June 1985 and April 2012 was conducted using variations of the following key terms: caries diagnostic methods, visual/tactile detection, FOTI, fiber optic transillumination, electrical conductance, bitewing radiographs, laser fluorescence, and DIAGNOdent (Table 2). This initial search identified 6,489 citations. Applying several inclusion and exclusion criteria (Table 3), we subjected the articles to title and abstract reviews, followed by full text review, to select a final number of 28 publications to be included in the meta-analysis.

Table 2. Initial literature search.

| Key Word | PubMed |
|---|---|
| Caries diagnostic methods | 3962 |
| Laser fluorescence AND dentistry | 427 |
| Laser fluorescence AND caries | 314 |
| Laser fluorescence AND caries diagnosis | 283 |
| Visual and tactile detection of dental caries | 24 |
| visual AND caries diagnosis | 432 |
| tactile AND caries diagnosis | 98 |
| bitewing radiographs AND caries | 461 |
| bitewing radiographs AND caries detection | 100 |
| FOTI AND caries | 36 |
| electrical conductance AND caries | 95 |
| DIAGNOdent | 199 |
| DIAGNOdent AND visual detection | 58 |
| **Total** | **6,489** |

Table 3. Inclusion and exclusion criteria.

| Inclusion Criteria | Exclusion Criteria |
|---|---|
| In vivo and in vitro studies involving human teeth | Studies that used bovine or other non-human teeth |
| Sensitivity and specificity reported, or calculable from reported data | Sensitivity and specificity not reported, or not calculable |
| Gold standard of histological sectioning or access into tooth structure to verify presence of decay | Teeth not analyzed using histological sectioning or access into tooth structure to verify presence of decay |
| Permanent teeth | Primary teeth |
| Occlusal, interproximal, and smooth surfaces | Systematic Reviews, meta-analyses, or studies that discussed caries diagnostic methods but did not present any results |
| Primary caries lesions | Secondary (recurrent) caries lesions |
| Studies using laser fluorescence, bitewing radiographs, visual/tactile, or fiber optic transillumination in caries diagnosis | |

Appendix A was constructed to present the studies included in our analysis. We recorded the following parameters for each study: 1) authors; 2) year of publication; 3) setting (*in vivo* or *in vitro*); 4) number of teeth or surfaces involved; 5) method of caries diagnosis; 6) number of examiners; 7) lesion prevalence (i.e., frequency); 8) sensitivity; and 9) specificity.

To facilitate comparisons among studies, we converted the sensitivity and specificity values of each diagnostic test to their standard scores, or normal deviate values ($Z_{caries}$ and $Z_{sound}$, respectively) (Appendix B) using an online calculator (59). According to Walker and Watkins (59),

> "This *z-value* or *z score* expresses the divergence of the experimental result x [in our case the sensitivity and specificity] from the most probable result μ as a number of standard deviations σ. The larger the value of *Z*, the less probable the experimental result is due to chance…Since the mean value and standard deviation depend upon the number of trials in the experiment, comparison between experiments with differing number of

trials is facilitated by standardizing the result: transforming it to a distribution with mean value zero and standard deviation of 1. A normally distributed experimental result x is thus standardized by subtracting the mean and dividing by the standard deviation of the experiment:"

$$z = (x - \mu) / \sigma$$

$Z_{caries}$ was then plotted against $Z_{sound}$ (Figure 1; Appendix C). The upward-sloping diagonal line represents all diagnostic test outcomes resulting from chance alone (59). $D_z$ represents the distance from a plotted point (i.e., Sn/Sp test result) to the diagonal line and "quantifies the performance above chance of the diagnostic test in a single value" (2). The $D_z$ value was calculated using the following formula:

$$D_z = (Z_{caries} - Z_{sound}) / \sqrt{2} .$$

Mean (± standard deviation) $D_z$ values were calculated for each diagnostic method. Mean values were compared via a two-way analysis of variance (ANOVA), with $D_z$ as the dependent variable and the following independent variables: 1) diagnostic method (four levels – visual/tactile examination, radiographic examination, laser fluorescence, and fiberoptic transillumination); 2) type of surfaces (three levels – occlusal, proximal, and facial/lingual smooth surface). Statistical analyses were accomplished using Statistical Package for the Social Sciences (SPSS) Version 18 computer software (SPSS, Inc., Chicago, IL). All significance levels were set at α = 0.05.

CHAPTER III: RESULTS

Results of the study are presented in Tables 6 through 9. Unweighted mean

sensitivity and specificity values (Table 4) were calculated for each diagnostic method

from the data obtained from the studies analyzed. Sensitivity values ranged from 0.361

for visual/tactile examination of proximal surfaces to 0.840 for fiber-optic

transillumination of occlusal surfaces. Fiber-optic transillumination had the highest

sensitivity values for occlusal surfaces. Laser fluorescence had the second highest mean

sensitivity value for occlusal surfaces and highest value for proximal surfaces.

Table 4. Mean sensitivity and specificity values for laser fluorescence, visual/tactile
examination, radiographs, and fiber-optic transillumination (FOTI).

| Diagnostic Method | Sensitivity | | Specificity | |
|---|---|---|---|---|
| | Surfaces | | Surfaces | |
| | Occlusal | Proximal | Occlusal | Proximal |
| Laser Fluorescence | 0.731 | 0.798 | 0.716 | 0.878 |
| Visual/Tactile Examination | 0.642 | 0.361 | 0.784 | 0.988 |
| Radiographs | 0.559 | 0.452 | 0.814 | 0.892 |
| Fiber-optic Transillumination | 0.840 | 0.424 | 0.843 | 0.910 |

Among the four diagnostic methods, the Specificity values ranged from 0.716

(laser fluorescence and occlusal surfaces) to 0.988 (visual/tactile examination of proximal

surfaces) (Table 4). Visual/tactile examination had the highest specificity (0.988) for

proximal surfaces, while having a value of 0.784 for the occlusal surface. Laser

fluorescence, had values of 0.716 and 0.878 for the occlusal and proximal surfaces,

respectively.

Statistical analysis (Table 5) revealed that the sensitivity of laser fluorescence (0.7415) was significantly higher than that of radiographs (0.4884), but statistically similar to fiber-optic transillumination and visual/tactile examination (p = 0.188). Likewise, there were no statistically significant differences in sensitivity among radiographs, fiber-optic transillumination, and visual/tactile examination. Similarly, there were no significant differences in specificity among any of the four diagnostic methods (p = 0.321).

Table 5. Statistical significance of sensitivity and specificity scores.*

| Statistical Significance | | | |
|---|---|---|---|
| Method | Sensitivity | | Specificity |
| Radiographs | 0.4884 | | 0.8560 |
| Fiber Optic | 0.6030 | 0.6030 | 0.8756 |
| Visual/Tactile | 0.6336 | 0.6336 | 0.8013 |
| Laser Fluorescence | | 0.7415 | 0.7403 |
| **Significance** | **0.433** | **0.188** | **0.321** |

* Two-way ANOVA and Tukey HSD post hoc tests (α = 0.05).

Table 8 presents the $D_z$ values for the four diagnostic methods in coordination with the occlusal and proximal surfaces. As discussed earlier, $D_z$ quantifies the performance above chance of the diagnostic test in a single value. When $D_z$ values are plotted graphically (as in Figure 1, Apendix C), the higher the $D_z$ value, the farther the plotted value is away from the diagonal line (representing chance), and the less likely the result is from chance. $D_z$ values ranged from 1.208 (laser fluorescence on occlusal surfaces) to 1.887 (fiberoptic transillumination on proximal surfaces). For all surfaces combined, fiber-optic transillumination exhibited the highest $D_z$ value (1.721), while

laser fluorescence had the lowest (1.365).    However, there were no statistically

significant differences in $D_z$ values among the four diagnostic methods (p = 0.930).

Table 6.  Mean $D_z$ values for laser fluorescence, visual/tactile examination, radiographs, and fiber-optic transillumination (FOTI).

| Diagnostic Method | Mean $D_z$ | | |
| --- | --- | --- | --- |
| | Surfaces | | |
| | Occlusal | Proximal | All Surfaces Combined |
| Laser Fluorescence | 1.208 | 1.523 | 1.256 |
| Visual/Tactile Examination | 1.468 | 1.841 | 1.516 |
| Radiographs | 1.635 | 1.212 | 1.476 |
| Fiberoptic Transillumination | 1.554 | 1.887 | 1.606 |

CHAPTER IV: DISCUSSION

This meta-analysis sought to evaluate the scientific evidence regarding the effectiveness of laser fluorescence, as compared to other caries diagnostic methods. In reviewing the extensive literature on this topic, there appeared to be a wide range of results (i.e., sensitivity and specificity values) with caries diagnostic aids that may easily lead to confusion regarding interpretation of their effectiveness.

Due to the vast number of studies that have been published, we chose to restrict this meta-analysis to studies that included only permanent teeth and primary decay, and that also used histologic sectioning as the "gold standard" confirmation for the presence of caries. We did not include studies (of which we found three) that verified the presence of decay by first opening the pits/fissures, followed by visual/tactile inspection. As compared to histologic sectioning, the process of opening of pits/fissures introduces more human error. However, in Akarsu and Koprulu's study (60), two examiners used visual inspection, bitewing radiographs, and laser fluorescence to verify the presence of decay. Agreement was needed before access was made into tooth structure to evaluate the extent of the decay. Similarly, with Chu, Lo, and You (61), two clinicians evaluated the patients via visual/tactile and radiographic examination. A third independent examiner evaluated the occlusal fissures using laser fluorescence, and there was a 10% random sampling of teeth on the same day to assess intra-examiner reliability. Patients were assumed to have fissure caries if the visual exam, radiographic exam, or DIAGNOdent had met study parameters (extent of decay into enamel or dentin/DIAGNOdent score of at least 20). Costa, de Paula, and Bezerra (22) used two examiners in the study, and for ethical reasons, opening of the fissures occurred only in cases when both examiners agreed on at

least one diagnostic method (visual, radiograph, and laser fluorescence) to the presence of dentin caries. I believe these three *in vivo* studies, with the standards they set for caries detection, were validated but we wanted to keep consistency in the diagnostic processes used in our analysis. However, I do believe that the ultimate standard in caries detection is still histologic sectioning, but this approach is not practical with *in vivo* studies.

Our literature search found five studies (28, 50, 62-64) that assessed the effectiveness of caries diagnostic methods for secondary caries and/or primary teeth. Although we did not include studies of secondary caries or primary teeth in this analysis, the literature suggests a variety of results. In a study involving primary teeth, Attrill and Ashley (64) found that sensitivities using laser fluorescence ranged from 0.77 to 0.80, while specificities were 0.82 to 0.85. Evaluating primary molars, Neuhaus and colleagues (62) reported sensitivity/specificity values of 0.68/0.84 with laser fluorescence, and 0.64/0.79 with bitewings radiographs. Braga and colleagues' (28) study of primary teeth and secondary decay revealed a sensitivity of 0.56 and specificity of 0.84 with laser fluorescence, while bitewing radiographs resulted in 0.48 (Sn) and 0.72 (Sp), and visual/tactile examinatoin had 0.75 (Sn) and 0.71 (Sp). However, I do believe it would be beneficial to compare the accuracy of various diagnostic aids with recurrent decay.

With the 28 studies selected for this analysis, there were variations with regard to the number of examiners and specimens (teeth) used within each. The sample sizes used within the 28 studies ranged from 25 up to 240 teeth. Those studies with 25 specimens [Baseren and Gokalp (65), Fung and colleagues (66)] had two and nine clinicians, respectively, to help compensate for the lower number of specimens. However, there

appear to be no differences in outcomes compared to the studies that presented more specimens. Differences in clinical experience and educational background can affect examiner decision-making (4). Among the studies we selected, none gave specific background information about the clinicians. Also, there were differences in the number of examiners, ranging from one clinician (42, 49, 26, 66-68) to as many as 34 (29). Studies utilizing multiple examiners may present a more realistic and representative range of the diagnostic devices; however, we did not exclude studies with only one examiner if the studies met our inclusion criteria.

We chose to perform the analysis by converting the sensitivity and specificity numbers to standard scores ($Z_{caries}$ and $Z_{sound}$), followed by calculating a $D_z$ value that represented the performance above chance of the diagnostic test in a single value. With this approach, we limited the strength of the individual studies since the number of teeth included in each study was negated. Also, the sensitivities and specificities were eventually combined to a single $D_z$ value, thus losing the individuality of those numbers. However, I observe sensitivity and specificity values with equal value. With their clinical relevance, it is not ideal to either leave untreated decay or to restore a surface that has no caries present. Both result in negative consequences.

CHAPTER V: CONCLUSION

In regards to the caries diagnostic methods observed in this analysis, there were no significant differences in respect to sensitivity, specificity, or $D_z$ values. Laser fluorescence had some of the highest values in regards to sensitivity, but rendered the lowest values with specificity. Laser fluorescence produced numbers that are comparable to the older and accepted diagnostic methods of visual/tactile and bitewing radiographs. In regards to clinical significance, laser fluorescence is a good adjunct to conventional caries diagnostic methods, but it is still lacking the consistency to be used on its own in the caries diagnostic process.

APPENDIX A

APPENDIX A

Literature and study parameters.

| Authors | Year | Setting (in vitro) | Number of Teeth | Dx Method | Number of Examiners | Lesion Prevalence | Sensitivity | Specificity |
|---|---|---|---|---|---|---|---|---|
| Alwas-Danowska H and colleagues | 2002 | In vitro | 49 molars | Observer #1 LF<br><br><br>Visual | 1 | Histologic section | 0.93 (1998)<br>1.00 (1999)<br><br>0.40 | 0.59 (1998)<br>0.50 (1999)<br><br>.94 |
| Alwas-Danowska H and colleagues | 2002 | In vitro | 49 molars | Observer #2 LF<br><br><br>Visual | 1 | Histologic section | 0.93 (1998)<br>0.93 (1999)<br>0.6 | 0.53 (1998)<br>0.47 (1999)<br>0.88 |
| Baseren N, Gokalp S | 2003 | In vitro | 25 molars | LF | 2 | Histologic section | 0.83 | 0.74 |
| Boston D | 2003 | In vitro | 150 teeth | Visual | 1 | Histologic section | 0.45 | 0.68 |
| Cortes D, Ellwood R, Ekstrand K | 2002 | In vitro | 111 molars | Visual | 1 | Histologic section | Enamel 0.97<br>Dentin 0.78 | Enamel 0.57<br>Dentin 0.83 |
| Cortes D, Ellwood R, Ekstrand K | 2002 | In vitro | 111 molars | FOTI | 1 | Histologic section | Enamel 0.96<br>Dentin 0.89 | Enamel 0.74<br>Dentin 0.92 |
| Cortes D, Ellwood R, Ekstrand K | 2002 | In vitro | 111 molars | LF | 1 | Histologic section | Enamel 0.72<br>Dentin 0.93 | Enamel 0.91<br>Dentin 0.72 |
|  |  |  |  |  |  |  |  |  |

| Authors | Year | Setting (in vitro) | Number of Teeth | Dx Method | Number of Examiners | Lesion Prevalence | Sensitivity | Specificity |
|---------|------|--------------------|-----------------|-----------|---------------------|-------------------|-------------|-------------|
| Cortes D, Ellwood R, Ekstrand K | 2002 | In vitro | 111 molars | ECM | 1 | Histologic section | Enamel 0.90 Dentin 0.81 | Enamel 0.83 Dentin 0.85 |
| de Paula A and colleagues | 2009 | In vitro | 26 molars – 64 occlusal sites | Visual | 2 | Histologic section | Enamel 0.63 Dentin 0.33 | Enamel 1.0 Dentin 0.95 |
| de Paula A and colleagues | 2009 | In vitro | 26 molars – 64 occlusal sites | LF | 2 | Histologic section | Enamel 0.72 Dentin 0.42 | Enamel 1.0 Dentin 0.65 |
| Downer MC, O'Mullane D | 1975 | In vitro | 109 teeth | Visual | 1 | Histologic exam | Pits and fissures 0.91 Smooth surface 0.94 | Pits and fissures 0.81 Smooth surface 0.92 |
| Downer MC, O'Mullane D | 1975 | In vitro | 109 teeth | Visual and Tactile | 1 | Histologic exam | Pits and fissures 0.92 Smooth surface 0.93 | Pits and fissures 0.85 Smooth surface 0.97 |
| Downer MC | 1989 | In vitro | 85 teeth | Visual | 1 | Histologic section | 0.62 | 0.85 |
| El-Housseiny and Jamjoum | 2001 | In vitro | 46 perm teeth | LF | 16 | Histologic section | 0.95 | 0.50 |
| El-Housseiny and Jamjoum | 2001 | In vitro | 46 perm teeth | Visual | 15 | Histologic section | 0.66 | 0.63 |

| Authors | Year | Setting (in vitro) | Number of Teeth | Dx Method | Number of Examiners | Lesion Prevalence | Sensitivity | Specificity |
|---|---|---|---|---|---|---|---|---|
| Fung L, Smales R, Ngo H, Mount G | 2004 | In vitro | 25 teeth - occlusal | LF | 9 | Histologic section | 0.65<br>0.69<br>0.54<br>0.63<br>0.19<br>0.56<br>0.77<br>0.50<br>0.75 | 0.88<br>0.89<br>0.92<br>0.96<br>0.97<br>0.82<br>0.78<br>0.71<br>0.86 |
| Huysmans M and colleagues | 1998 | In vitro | 107 extracted premolars and molars | BW | 2 | Histologic section | 0.58 | 0.87 |
| Huysmans M and colleagues | 1998 | In vitro | 107 extracted premolars and molars | Visual | 2 | Histologic section | 0.27 | 1.0 |
| Huysmans M and colleagues | 1998 | In vitro | 107 extracted premolars and molars | ECM – Airflow method ECM - surface | 2 | Histologic section | ECM airflow 0.58 ECM surface 0.76 | ECM airflow 0.94 ECM surface 0.90 |
| Jablonski-Momeni A and colleagues | 2010 | In vitro | 100 teeth | LF | 1 for solid teeth, 1 for teeth after sectioned | Histologic section | Enamel 0.82 Dentin 0.54 | Enamel 0.48 Dentin 0.89 |
| Kay and colleagues | 1988 | In vitro | 30 teeth | Visual of occlusal surfaces | 10 | Histologic section | 0.57 | 0.67 |

| Authors | Year | Setting (in vitro) | Number of Teeth | Dx Method | Number of Examiners | Lesion Prevalence | Sensitivity | Specificity |
|---|---|---|---|---|---|---|---|---|
| Ketly C, Holt R | 1993 | In vitro | 100 molars | BW for occlusal surfaces | 2 | Histologic section | 0.67 | 0.92 |
| Ketly C, Holt R | 1993 | In vitro | 100 molars | Visual | 2 | Histologic section | 0.31 | 0.98 |
| Lussi A | 1991 | In vitro | 61 teeth | Visual | 34 dentists | Histologic section | 0.65 | 0.83 |
| Lussi A | 1991 | In vitro | 61 teeth | Visual/ Tactile | 34 dentists | Histologic section | 0.61 | 0.87 |
| Lussi A and colleagues | 1999 | In vitro | 105 teeth – occlusal surfaces | ECM | 11 | Histologic section | 0.90 | 0.71 |
| Lussi A and colleagues | 2006 | In vitro | 75 molars / 150 sites | LF | 5 | Histologic section | Enamel 0.88 Dentin 0.89 | Enamel 0.92 Dentin 0.82 |
| Lussi A and colleagues | 2006 | In vitro | 75 molars / 150 sites | BW | 5 | Histologic section | Enamel 0.68 Dentin 0.45 | Enamel 0.67 Dentin 0.89 |
| Nytun R and colleagues | 1992 | In vitro | 30 perm molars | BW | 10 | Histologic section | 0.66 | 0.50 |
| Nytun R and colleagues | 1992 | In vitro | 30 perm molars | Visual | 10 | Histologic section | 0.72 | 0.41 |
| Peers A and colleagues | 1993 | In vitro | 240 teeth | FOTI | 1 | Histologic section | 0.67 | 0.97 |
| Peers A and colleagues | 1993 | In vitro | 240 teeth | Visual | 1 | Histologic section | 0.38 | 0.99 |
| Peers A and colleagues | 1993 | In vitro | 240 teeth | BW | 1 | Histologic section | 0.59 | 0.96 |

| Authors | Year | Setting (in vitro) | Number of Teeth | Dx Method | Number of Examiners | Lesion Prevalence | Sensitivity | Specificity |
|---|---|---|---|---|---|---|---|---|
| Reis A and colleagues | 2006 | In vivo and in vitro | 57 3<sup>rd</sup> molars | Visual | 2 | Intraorally then histologic evaluation following extraction | Enamel 0.75 Dentin 0.69 | Enamel 0.55 Dentin 0.88 |
| Reis A and colleagues | 2006 | In vitro | 57 3<sup>rd</sup> molars | LF | 2 | Intraorally then histologic evaluation following extraction | Enamel 0.71 Dentin 0.78 | Enamel 0.57 Dentin 0.63 |
| Ricketts D and colleagues | 1995 | In vitro | 48 molars | Visual | 12 | Histologic exam | 0.49 | 0.90 |
| Ricketts D and colleagues | 1995 | In vitro | 48 molars | BW | 12 | Histologic exam | 0.62 | 0.76 |
| Rodrigues J and colleagues | 2009 | In vitro | 148 teeth | Visual | 2 | Histologic section | Enamel 0.40 Dentin 0.88 | Enamel .97 Dentin 0.46 |
| Rodrigues J and colleagues | 2009 | In vitro | 148 teeth | LF | 2 | Histologic section | Enamel 0.92 Dentin 0.82 | Enamel 0.53 Dentin 0.28 |
| Russel M and Pitts | 1993 | In vitro | 240 sites | LF | 3 | Histologic section | 0.26 | 0.90 |
| Shi XQ and colleagues | 2001 | In vitro | 40 teeth | QLF | 1 | Histologic section | 0.94 | 1.0 |
| Shi XQ and colleagues | 2001 | In vitro | 40 teeth | LF | 1 | Histologic section | 0.75 | 0.96 |
| Valera F and colleagues | 2008 | In vitro | 72 teeth occlusals | Visual | 3 | Histologic section | 0.44 | 1.0 |
| Valera F and colleagues | 2008 | In vitro | 72 teeth occlusals | BW | 3 | Histologic section | 0.12 | 0.98 |

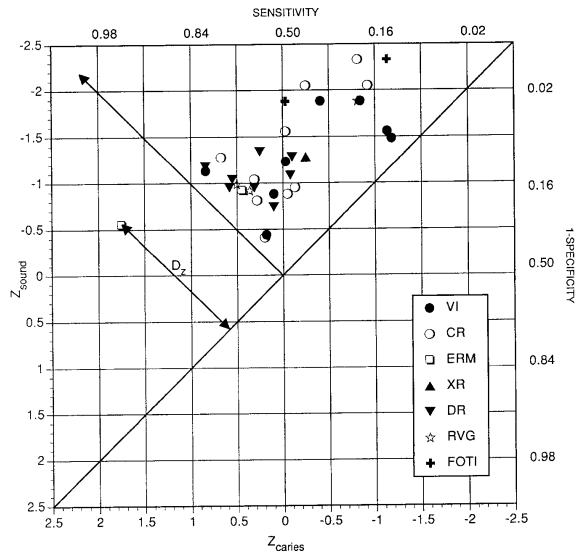| Authors | Year | Setting (in vitro) | Number of Teeth | Dx Method | Number of Examiners | Lesion Prevalence | Sensitivity | Specificity |
|---|---|---|---|---|---|---|---|---|
| Valera F and colleagues | 2008 | In vitro | 72 teeth | LF | 3 | Histologic section | 0.33 | 1.0 |
| Wenzel A and colleagues | 2002 | In vitro | 190 teeth | Digital BW – 2 systems | 4 | Histologic section | Digital BW system 1 Enamel 0.27 Dentin 0.37 Digital BW system 2 Enamel 0.33 Dentin 0.41 | Digital BW system 1 Enamel 0.95 Dentin 0.96 Digital BW new system 2 Enamel 0.94 Dentin 0.94 |
| White and Yoon | 2000 | In vitro | 80 teeth | BW | 12 | Histologic section | Enamel .4-.42 Dentin .61-.63 All lesions .52-.54 | Enamel .75-.78 Dentin .91-.92 All lesions .75-.78 |

APPENDIX B

Calculation of standard score (*z*-score) values from Sensitivity/Specificity data.

| Study Number | Method | Surface | Sn | Sp | 1 - Sp | Z caries | Z Sound | Difference | $D_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | LF | Occl | 0.95 | 0.52 | 0.48 | 1.645 | -0.05 | 1.695 | 1.199 |
| | Visual | Occl | 0.51 | 0.91 | 0.09 | 0.025 | -1.341 | 1.366 | 0.966 |
| 2 | LF | Occl | 0.83 | 0.74 | 0.26 | 0.954 | -0.643 | 1.597 | 1.129 |
| 3 | Visual | Occl | 0.97 | 0.57 | 0.43 | 1.881 | -0.176 | 2.057 | 1.454 |
| | Visual | Occl | 0.78 | 0.83 | 0.17 | 0.772 | -0.954 | 1.726 | 1.220 |
| | FOTI | Occl | 0.96 | 0.74 | 0.26 | 1.751 | -0.643 | 2.394 | 1.692 |
| | FOTI | Occl | 0.89 | 0.92 | 0.08 | 1.227 | -1.405 | 2.632 | 1.861 |
| | LF | Occl | 0.72 | 0.91 | 0.09 | 0.583 | -1.341 | 1.924 | 1.360 |
| | LF | Occl | 0.93 | 0.72 | 0.28 | 1.476 | -0.583 | 2.059 | 1.455 |
| | ECM | Occl | 0.9 | 0.83 | 0.17 | 1.282 | -0.954 | 2.236 | 1.581 |
| | ECM | Occl | 0.81 | 0.85 | 0.15 | 0.878 | -1.036 | 1.914 | 1.353 |
| 4 | Visual | Occl | 0.63 | 1 | 0 | 0.332 | -6 | 6.332 | 4.477 |
| | Visual | Occl | 0.33 | 0.95 | 0.05 | 0.439 | -1.645 | 2.084 | 1.473 |
| | LF | Occl | 0.72 | 1 | 0 | 0.583 | -6 | 6.583 | 4.654 |
| | LF | Occl | 0.42 | 0.65 | 0.35 | 0.202 | -0.385 | 0.587 | 0.415 |
| 5 | Visual | Occl | 0.92 | 0.85 | 0.15 | 1.405 | -1.036 | 2.441 | 1.726 |
| | Visual | Smooth | 0.93 | 0.97 | 0.03 | 1.476 | -1.881 | 3.357 | 2.373 |
| 6 | Visual | Occl | 0.62 | 0.85 | 0.15 | 0.305 | -1.036 | 1.341 | 0.948 |
| 7 | LF | Occl | 0.95 | 0.5 | 0.5 | 1.645 | | 1.645 | 1.163 |
| | Visual | Occl | 0.66 | 0.63 | 0.37 | 0.412 | -0.332 | 0.744 | 0.526 |
| 8 | LF | Occl | 0.59 | 0.87 | 0.13 | 0.228 | -1.126 | 1.354 | 0.957 |
| 9 | Dig Xray | Occl | 0.58 | 0.87 | 0.13 | 0.202 | -1.126 | 1.328 | 0.939 |
| | Visual | Occl | 0.27 | 1 | 0 | 0.613 | -6 | 6.613 | 4.676 |
| | ECM | Occl | 0.58 | 0.94 | 0.06 | 0.202 | -1.555 | 1.757 | 1.242 |
| | ECM | Occl | 0.76 | 0.9 | 0.1 | 0.706 | -1.282 | 1.988 | 1.405 |
| 10 | Visual | Occl | 0.91 | 0.54 | 0.46 | 1.341 | -0.1 | 1.441 | 1.018 |
| | Visual | Occl | 0.7 | 0.91 | 0.09 | 0.524 | -1.341 | 1.865 | 1.318 |
| | LF | Occl | 0.82 | 0.48 | 0.52 | 0.915 | 0.05 | 0.865 | 0.611 |
| | LF | Occl | 0.54 | 0.89 | 0.11 | 0.1 | -1.227 | 1.327 | 0.938 |
| 11 | Visual | Occl | 0.57 | 0.67 | 0.33 | 0.176 | -0.439 | 0.615 | 0.434 |
| 12 | Conv Xray | Occl | 0.67 | 0.92 | 0.08 | 0.439 | -1.405 | 1.844 | 1.303 |
| | Conv Xray | Occl | 0.93 | 0.89 | 0.11 | 1.476 | -1.227 | 2.703 | 1.911 |
| | Visual | Occl | 0.31 | 0.98 | 0.02 | 0.496 | -2.054 | 2.55 | 1.803 |
| | Visual | Occl | 0.45 | 1 | 0 | 0.126 | -6 | 6.126 | 4.331 |
| 13 | Visual | Occl | 0.65 | 0.83 | 0.17 | 0.385 | -0.954 | 1.339 | 0.946 |
| | Vis/Tact | Occl | 0.61 | 0.87 | 0.13 | 0.279 | -1.126 | 1.405 | 0.993 |
| 14 | LF | Occl | 0.85 | 0.75 | 0.25 | 1.036 | -0.674 | 1.71 | 1.209 |
| | LF | Occl | 0.8 | 0.83 | 0.17 | 0.842 | -0.954 | 1.796 | 1.269 |
| | ECM | Occl | 0.9 | 0.71 | 0.29 | 1.282 | -0.553 | 1.835 | 1.297 |
| 15 | LF | Interprox | 0.88 | 0.92 | 0.08 | 1.175 | -1.405 | 2.58 | 1.824 |
| | LF | Interprox | 0.89 | 0.82 | 0.18 | 1.227 | -0.915 | 2.142 | 1.514 |
| | Conv Xray | Interprox | 0.68 | 0.67 | 0.33 | 0.468 | -0.439 | 0.907 | 0.641 |
| | Conv Xray | Interprox | 0.45 | 0.89 | 0.11 | 0.126 | -1.227 | 1.353 | 0.956 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 16 | Conv Xray | Occl | 0.66 | 0.5 | 0.5 | 0.412 | | 0.412 | 0.291 |
| 17 | Visual | Occl | 0.72 | 0.41 | 0.59 | 0.583 | 0.228 | 0.355 | 0.251 |
| 18 | FOTI | Interprox | 0.67 | 0.97 | 0.03 | 0.439 | -1.881 | 2.32 | 1.640 |
| | Visual | Interprox | 0.38 | 0.99 | 0.01 | 0.305 | -2.326 | 2.631 | 1.860 |
| | Conv Xray | Interprox | 0.59 | 0.96 | 0.04 | 0.228 | -1.751 | 1.979 | 1.399 |
| 19 | Visual | Occl | 0.77 | 0.73 | 0.27 | 0.739 | -0.613 | 1.352 | 0.956 |
| | Visual | Occl | 0.75 | 0.58 | 0.42 | 0.674 | -0.202 | 0.876 | 0.619 |
| | Visual | Occl | 0.72 | 0.84 | 0.16 | 0.583 | -0.994 | 1.577 | 1.115 |
| | Visual | Occl | 0.75 | 0.55 | 0.45 | 0.674 | -0.126 | 0.8 | 0.565 |
| | Visual | Occl | 0.69 | 0.88 | 0.12 | 0.496 | -1.175 | 1.671 | 1.181 |
| | LF | Occl | 0.8 | 0.43 | 0.57 | 0.842 | 0.176 | 0.666 | 0.470 |
| | LF | Occl | 0.75 | 0.52 | 0.48 | 0.674 | -0.05 | 0.724 | 0.511 |
| | LF | Occl | 0.71 | 0.57 | 0.43 | 0.553 | -0.176 | 0.729 | 0.515 |
| | LF | Occl | 0.78 | 0.63 | 0.37 | 0.772 | -0.332 | 1.104 | 0.780 |
| | LF | Occl | 0.72 | 0.73 | 0.27 | 0.583 | -0.613 | 1.196 | 0.845 |
| 20 | Visual | Occl | 0.49 | 0.9 | 0.1 | 0.025 | -1.282 | 1.307 | 0.924 |
| | Conv Xray | Occl | 0.62 | 0.76 | 0.24 | 0.305 | -0.706 | 1.011 | 0.714 |
| 21 | Visual | Occl | 0.4 | 0.97 | 0.03 | 0.253 | -1.881 | 2.134 | 1.508 |
| | Visual | Occl | 0.88 | 0.46 | 0.54 | 1.175 | 0.1 | 1.075 | 0.760 |
| | LF | Occl | 0.92 | 0.53 | 0.47 | 1.405 | -0.075 | 1.48 | 1.046 |
| | LF | Occl | 0.82 | 0.28 | 0.72 | 0.915 | 1.372 | -0.457 | -0.323 |
| 22 | LF | Occl | 0.7 | 0.77 | 0.23 | 0.524 | -0.739 | 1.263 | 0.893 |
| | LF | Occl | 0.63 | 0.89 | 0.11 | 0.332 | -1.227 | 1.559 | 1.102 |
| | LF | Occl | 0.63 | 0.77 | 0.23 | 0.332 | -0.739 | 1.071 | 0.757 |
| | LF | Occl | 0.63 | 0.87 | 0.13 | 0.332 | -0.739 | 1.071 | 0.757 |
| 23 | LF | Occl | 0.26 | 0.9 | 0.1 | 0.643 | -1.282 | 1.925 | 1.361 |
| 24 | DIFOTI | Interprox | 0.56 | 0.76 | 0.24 | 0.151 | -0.706 | 0.857 | 0.605 |
| | DIFOTI | Occl | 0.67 | 0.87 | 0.13 | 0.439 | -1.126 | 1.565 | 1.106 |
| | DIFOTI | Smooth | 0.43 | 0.87 | 0.13 | 0.176 | -1.126 | 1.302 | 0.920 |
| | Conv Xray | Interprox | 0.21 | 0.91 | 0.09 | 0.806 | -1.341 | 2.147 | 1.518 |
| | Conv Xray | Occl | 0.18 | 0.98 | 0.02 | 0.915 | -2.054 | 2.969 | 2.099 |
| | Conv Xray | Smooth | 0.04 | 0.96 | 0.04 | 1.751 | -1.751 | 3.502 | 2.476 |
| 25 | DD | Interprox | 0.75 | 0.96 | 0.04 | 0.674 | -1.751 | 2.425 | 1.714 |
| 26 | Visual | Occl | 0.44 | 1 | 0 | 0.151 | -6 | 6.151 | 4.349 |
| | Conv Xray | Occl | 0.12 | 0.98 | 0.02 | 1.175 | -2.054 | 3.229 | 2.283 |
| | LF | Occl | 0.33 | 1 | 0 | 0.439 | -6 | 6.439 | 4.553 |
| 27 | Dig Xray | Interprox | 0.27 | 0.95 | 0.05 | 0.613 | -1.645 | 2.258 | 1.596 |
| | Dig Xray | Interprox | 0.37 | 0.96 | 0.04 | 0.332 | -1.751 | 2.083 | 1.472 |
| | Dig Xray | Interprox | 0.33 | 0.94 | 0.06 | 0.439 | -1.555 | 1.994 | 1.409 |
| | Dig Xray | Interprox | 0.41 | 0.94 | 0.06 | 0.228 | -1.555 | 1.783 | 1.260 |
| 28 | Conv Xray | Interprox | 0.41 | 0.76 | 0.24 | 0.228 | -0.706 | 0.934 | 0.660 |
| | Conv Xray | Interprox | 0.62 | 0.91 | 0.09 | 0.305 | -1.341 | 1.646 | 1.163 |

APPENDIX C

Figure 1.  Normal-deviate values of $Z_{carie}$ (sensitivity) plotted against $Z_{sound}$ (1 − specificity). (VI = Visual Inspection; CR = Conventional Radiography; ERM = Electrical Resistance Measurement; XR = XeroRadiography; DR = Digital Radiography; RVG = RadioVisioGraphy; FOTI = Fiber-Optic transillumination)



* Adapted from: Ie YL, Verdonschot EH.  Performance of diagnostic systems in occlusal caries detection compared.  Community Dent Oral Epidemiol 1994; 22(3): 187-191.  Reprinted with permission from the publisher.

REFERENCES

1. Anderson M.  Risk assessment and epidemiology of dental caries:  review of literature.  Pediatr Dent 2002; 24(5): 377-385.

2. Bader J, Shugars D.  A systematic review of the performance of methods for identifying carious lesions. J Pub Health Dent 2002; 62(4): 201-213.

3. Bader JD, Brown JP.  Dilemmas in caries diagnosis. J Am Dent Assoc 1993; 124(6): 48-50.

4. Bader JD, Shugars DA.  Variation in dentists' clinical decisions.  J Public Health Dent 1995; 55(3): 181-188.

5. Shugars D, Hayden W, Crall J, Scurria M.  Variation in the use of crowns and their alternatives.  J Dent Educ. 1997; 61(1): 22-28.

6. American Dental Association.  Principles of ethics and code of professional conduct. 2003; 134(1): 1-20.

7. Beltran-Aguilar EG, Estupinan-Day S, Baez R.  Analysis of prevalence and trends of dental caries in the Americas between the 1970's and 1990's.  Int Dent J 1999; 49(6): 322-329

8. Marthaler TM, O'Mullane DM, Vrbic V.  The prevalence of dental caries in Europe 1990-1995.  Caries Res 1996; 30(1): 237-255.

9. Brunelle JA, Carlos JP.  Recent trends in dental caries in U.S. children and the effects of water fluoridation.  J Dent Res 1990; 69(Spec Iss): 723-727.

10. Kaste LM, Selwitz RH, Oldakowski RJ, Brunelle JA, Winn DM, Brown LJ.  Coronal caries in the primary and permanent dentition of children and adolescents 1-17 years of age: United States, 1988-1991.  J Dent Res 1996; 75(Spec Iss): 631-641.

11. Brown JL, Wall TP, Lazar V.  Trends in total caries experience: Permanent and primary teeth.  J Am Dent Assoc 2000; 131(2): 223-231.

12. Brown JL, Wall TP, Lazar V.  Trends in caries among adults 18 to 45 years old.  J Am Dent Assoc 2002; 133(7): 827-834.

13. Bratthall D, Hansel-Petersson G, Sndberg H.  Reasons for the caries decline: What do the experts believe?  Eur Oral Sci 1996; 104 (4(Pt 2)):  416-422.

14. Marthaler TM.  Changes in dental caries 1953-2003.  Caries Res 2004; 38(3): 173-181.

15. Zandona A, Zero D.  Diagnostic tools for early caries detection.  J Am Dent Assoc 2006; 137(12): 1675-1684.

16. Kidd EA, Mejare I, and Nyvad B.  (2003).  Clinical and radiographic diagnosis.   In O. Fejerskov and EAM Kidd, Dental Caries: The Disease and its Clinical Management.  Oxford, UK: Blackwell Munksgaard; pp. 111-128.

17. van Rijkom HM, Verdonschot EH.  Factors involved in validity measurements of diagnostic tests for approximal caries – A meta-analysis.  Caries Res 1995; 29(5) 364-370.

18. Ricketts D, Kidd E, Weerheijm K.  Hidden caries:  what is it:  Does it exist?  Does it matter?  Int Dent J 1997; 47(5): 259-265.

19. Espelid A, Tveit A.  Diagnosis of secondary caries and crevices adjacent to amalgam.  Int Dent J 1991; 41(6): 359-364.

20. Hume W.  Need for change in standards of caries diagnosis:  perspective based on the structure and behavior of the caries lesion.  J Dent Educ 1993; 57(6): 439-443.

21. Hopcraft M, Morgan M.  Comparison of radiographic and clinical diagnosis of approximal and occlusal dental caries in a young adult population.  Community Dent Oral Epi 2005; 33(2): 212-218.

22. Costa A, de Paula L, Bezerra A.  Use of DIAGNOdent for diagnosis of non-cavitated occlusal dentin caries.  J Appl Oral Sci 2008; 16(1): 18-23.

23. Ekstrand K, Qvist V, Thylstrup A.  Light microscope study of the effect of probing in occlusal surfaces.  Caries Res 1987; 21(4): 368-374.

24. van Dorp CS, Exterkate RA, ten Cate JM.  The effect of dental probing on subsequent enamel demineralization.  J Dent Child 1988; 55(5): 343-347.

25. Pretty I, Maupome G.  A closer look at diagnosis in clinical dental practice:  Part I. Reliability, validity, specificity and sensitivity of diagnostic procedures.  J Can Dent Assoc 2004; 70(4): 251-55.

26. Fracaro M, Seow W, McAllan L, Purdie D.  The sensitivity and specificity of clinical assessment compared with bitewing radiography for detection of occlusal dentin caries.  Am Acad Ped Dent 2001; 23(3): 204-210.

27. Valera F, Pessan J, Valera R, Mondelli J, Percinoto C.  Comparison of visual inspection, radiographic examination, laser fluorescence and their combinations on treatment decisions for occlusal surfaces.  Am J Dent 2008; 21(1): 25-29.

28. Braga M, Chiarotti A, Imparato J, Mendes F.  Validity and reliability of methods for the detection of secondary caries around amalgam restorations in primary teeth. Braz Oral Res 2010; 24(1): 102-107.

29. Lussi A.  Validity of diagnostic and treatment decisions of fissure caries.  Caries Res 1991; 25(4): 296-303.

30. Maggio MP, Villegas H, Blatz MB.  The effect of magnification loupes on the performance of preclinical dental students.  Quintessence Int 2011; 42(1): 45-55.

31. Friedman MJ.  Magnification in a restorative dental practice:  from loupes to microscopes.  Compend Contin Educ Dent 2004; 25(1): 53-55.

32. Eichenberger M, Perrin P, Neuhaus KW, Bringolf U, Lussi A.  Influence of loupes and age on the near visual acuity of practicing dentists.  J Biomed Opt 2011; 16(3): 035003.

33. Christensen GJ.  Magnification in dentistry:  useful tool or another gimmick?  J Am Dent Assoc 2003; 134(12): 1647-1650.

34. Christensen G.  Why switch to digital radiography.  J Am Dent Assoc 2004; 135(10): 1437-1439.

35. Ricketts D, Kidd E, Weerheijm K.  Hidden caries: What is it?  Does it exist?  Does it matter?  Int Dent J 1997; 47(5): 259-265.

36. De Paula A, Campos J, Diniz M, Hebling J, Rodrigues J.  In situ and in vitro comparison of laser fluorescence with visual inspection in detecting occlusal caries lesions.  Lasers Med Sci 2009 26(1); 10-15.

37. Navarro L, Puy M, Godoy F.  Diagnostic performance of radiovisiongraphy in combination with a diagnosis assisting program versus conventional radiography and radiovisiography in basic mode and with magnification.  Med Oral Pathol 2008; 13(4): E261-265.

38. Anbiaee N, Mohassel AR, Imanimoghaddam M, Moazzami SM.  A comparison of the accuracy of digital and conventional radiography in the diagnosis of recurrent caries.  J Contemp Dent Pract 2010; 11(6): E025-32.

39. Dias da Silva PR, Martins Marques M, Steagall W Jr, Medeiros Mendes F, Lascala CA.  Accuracy of direct digital radiography for detecting occlusal caries in primary teeth compared with conventional radiography and visual inspection:  an in vitro study.  Dentomaxillofac Radiol 2010; 39(6): 362-367.

40. Chong MJ, Seow WK, Purdie DM, Cheng E, Wan V. Visual-tactile examination compared with conventional radiography, digital radiography, and DIAGNOodent in the diagnosis of occlusal occult caries in extracted premolars. Ped Dent 2003; 25(4): 341-349.

41. Wu J, Donly Z, Donly K, Hackmyer S. Demineralization depth using QLF and a novel image processing software. Int J Dent 2010; 28(4): 36-46.

42. Cortes D, Ellwood R, Ekstrand K. An in vitro comparison of a combined FOTI/visual examination of occlusal caries with other caries diagnostic methods and the effect of stain on their diagnostic performance. Caries Res 2003; 37(1): 8-16.

43. Hintze H, Wenzel A, Danielsen B, Nyvad B. Reliability of visual examination, fiber-optic transillumination, and bite-wing radiography, and reproducibility of direct visual examination following tooth separation for the identification of cavitated carious lesions in contacting approximal surfaces. Caries Res 1998; 32(2): 204-209.

44. Mitropoulos C. A comparison of fibre-optic transillumination with bitewing radiographs. Br Dent J 1985; 159(1): 21-23.

45. Longbottom C. Electrical measurements for use in caries clinical trials. J Dent Res 2004; 83(1): 76-79.

46. Lussi A, Imwinkelried S, Pitts N, Longbottom C, Reich E. Performance and reproducibility of a laser fluorescence system for detection of occlusal caries in vitro. Caries Res 1999; 33(10): 261-266.

47. Huysmans M, Longbottom C, Pitts N. Electrical methods in occlusal caries diagnosis: An in vitro comparison with visual inspection and bite-wing radiography. Caries Res 1998; 32(10): 324-329.

48. Hibst R, Paulus R. Caries detection by red excited fluorescence: investigations on fluorophores. Caries Res 1999; 33(2): 295-298.

49. Shi X, Traneus S, Angmar-Mansson B. Comparison of QLF and DIAGNOdent for quantification of smooth surface caries. Caries Res 2000; 35(1): 21-26.

50. Bamzahim M, Angmar-Mansson B. Secondary caries detection by DIAGNOdent and radiography: a comparative in vitro study. Acta Odont Scand 2004; 62(1): 61-64.

51. Apostolopoulou D, Lagouvardos P, Kavvadia K, Papagiannoulis L. Histological validation of a laser fluorescence device for occlusal caries detection in primary molars. Eur Acad Ped Den 2009; 10(1): 11-15.

52. Bamzahim M, Abdulaziz A, Shi X.  Clinical performance of DIAGNOdent in the detection of secondary carious lesions.  Acta Odont Scandinavia, 2005; 63: 26-30.

53. Diniz M, Rodrigues J, Hug I, Cordeiro R, Lussi A.  The influence of pit and fissure sealants on infrared fluorescence measurements.  Caries Res 2008; 42(5): 328-33.

54. Krause F, Braun A, Frentzen M, Jepsen S.  Effects of composite fissure sealants on IR laser fluorescence measurements.  Lasers Med Sci 2008; 23(2): 133-139.

55. Lussi A, Francescut P.  Performance of conventional and new methods for the detection of occlusal caries in deciduous teeth.  Caries Res 2003; 37(1): 2-7.

56. Boston D.  Initial in vitro evaluation of DIAGNOdent for detecting secondary carious lesions associated with resin composite restorations.  Quintessence Int 2003; 34(2): 109-16.

57. Lussi A, Hibst R, Paulus R.  DIAGNOdent:  An optical method for caries detection.  J Dent Res 2004; 83(C): 80-83.

58. http://www.thecanarysystem.com

59. Walker J, Watkins M.  University of Kent at Canterbury.  http://www.fourmilab.ch/rpkp/experiments/analysis/zCalc.html

60. Akarsu S, Koprulu H.  In vivo comparison of the efficacy of DIAGNOdent by visual inspection and radiographic diagnostic techniques in the diagnosis of occlusal caries.  J Clin Dent 2006; 17(3): 53-55.

61. Chu C, Lo E, You D.  Clinical diagnosis of fissure caries with conventional and laser-induced fluorescence techniques.  Las Med Sci 2010; 25(3): 355-362.

62. Neuhaus K, Rodrigues J, Seemann R, Lussi A.  Detection of proximal secondary caries at cervical class II amalgam restoration margins in vitro.  J Dent 2012; 127(2): 1-7.

63. Goel A, Chawla H, Gauba , Goyal A.  Comparison of validity of DIAGNOdent with conventional methods for detection of occlusal caries in primary molars using the histological gold standard:  an in vivo study.  J Ind Soc Pedod Prev Dent 2009; 27(4): 227-234.

64. Attrill D, Ashley P.  Occlusal caries detection in primary teeth:  a comparison of DIAGNOdent with conventional methods?  Br Dent J 2001; 190(8): 440-443.

65. Baseren N, Gokalp S. Validity of a laser fluorescence system (DIAGNOdent) for detection of occlusal caries in third molars: an in vitro study. J Oral Rehab 2003; 30(12): 1190-1194.

66. Fung L, Smales R, Ngo H, Mount G. Diagnostic comparison of three groups of examiners using visual and laser fluorescence methods to detect occlusal caries in vitro. Aus Dent J 2004; 49(2): 67-71.

66. Alwas-Danowska H, Plasschaert A, Suliborski S, Verdonschot E. Reliability and validity of laser fluorescence measurements in occlusal caries diagnosis. J Dent 2002; 30(4): 129-134.

67. Downer M, O'Mullane D. A comparison of the concurrent validity of two epidemiologic diagnostic systems for caries evaluation. Community Dent Oral Epidemiol 1975; 3(1): 20-24.

68. Peers A, Hill F, Mitropoulos C, Holloway P. Validity and reproducibility of clinical examination, fibre-optic transillumination, and bite-wing radiology for the diagnosis of small approximal carious lesions: an in vitro study. Caries Res 1993; 27(4): 307-311

69. Rodrigues J, Hug I, Neuhaus K, Lussi A. Light-emitting diode and laser fluorescence-based devices in detecting occlusal caries. J Bio Optics 2011; 16(10): 45-49.

70. Reis A, Mendes F, Angnes V, Angnes G, Grande R, Loguercio A. Performance of methods of occlusal caries detection in permanent teeth under clinical and laboratory conditions. J Dent 2006; 34(2): 89-96.